

The University of Chicago

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A PART OF A DISSERTATION SUBMITTED TO THE FACULTY OF THE
DIVISION OF THE PHYSICAL SCIENCES IN CANDIDACY FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOGRAPHY

1935

BY

JOHN KERR ROSE

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CORN YIELD AND CLIMATE IN THE CORN BELT

John Kerr Rose
University of Chicago

THE correlation of variations in corn yield with fluctuations of climatic factors is more than an academic problem. Many of the human activities prominent in the Corn Belt, rural or urban, are directly or indirectly related to corn. Beginning with the preparation of the seedbed in spring and extending intermittently through the harvesttime of late autumn, the larger part of the Corn Belt farmer's time and activities is applied to corn. Wintertime activities include the feeding of animals with corn. Corn Belt villages exist mainly to serve the corn grower. The cities buy, process, and sell the products of the cornland and serve the corn farmer in many other ways. The average yearly value of the corn crop of the United States is roughly one twenty-fifth the total value of all plant products grown in the world suitable for human or animal food.

In recent years corn has occupied yearly about 100,000,000 acres¹ of land in the United States—roughly five times the total area of Indiana. Of these 100,000,000 acres, more than 60 per cent² lie in the ten states of which parts are included in the geographical division known as the Corn Belt. On an average, about 19 per cent³ of the area of Iowa is planted to corn. In the heart of the Corn Belt, however, as much as 40 to 50 per cent of the area is in corn yearly. Here no other crop so dominates the landscape. Corn is king.

Perhaps no other thing about the corn crop is so interlocked with the weal and woe of the Corn Belt inhabitants as the yearly variation in yield. The corn crop of the United States fluctuates from about one and a half to about three billion bushels.⁴ The yield per unit area fluctuates notably from year to year. For the state of Indiana, some years give an average per-acre yield more than twice as large as some other years. Iowa, commonly considered a relatively stable state climatically, in some years has an average per-acre yield 300 per cent greater than in others.

No other factor affecting the yield of corn from year to year in a given area fluctuates as does weather, or the longer phase of weather, climate. Soil fertility is more or less constant, as is the care given the crop. Varieties are changed slowly. Reed⁵ has found that in Iowa

¹ *Yearbook of Agric.*, 1932, U. S. Dept. of Agriculture, Washington, 1932, p. 608.

² W. A. Mattice: Weather and Corn Yields, *Monthly Weather Rev.*, Vol. 59, 1931, pp. 105-112; reference on p. 105.

³ *Ibid.*, p. 106, Fig. 1.

⁴ *Yearbook of Agric.*, 1932, loc. cit.

⁵ C. D. Reed: Weather and Corn Maturity in Iowa, *Monthly Weather Rev.*, Vol. 55, 1927, pp. 485-488.

the yield has increased slowly over a long period of years, owing, perhaps, in the main to better varieties and improved tillage but possibly also to changes in climate. Insect pests are a variable affecting the crop; insect damage, however, correlates fairly well with drought conditions. Thus climatic factors would seem to be the most potent and hence the most worthy of investigation among those causing fluctuations in the yield of this major crop. The tropical or subtropical origin of corn and the wide variety of climatic conditions even within the Corn Belt suggest that there may well be interesting and peculiar responses to the climate under which corn is now so largely grown.

EARLIER INVESTIGATIONS

It is not surprising that so important a problem early received attention from scientists. Wren,⁶ writing in 1901, summarized the existing knowledge and theories concerning corn yield as related to climate. The earlier investigations dealt with temperature more than with any other factor and made no use of mathematical correlation.

Since that time a number of studies, mostly utilizing mathematical correlation, have been published on the various phases of the relation between corn yield and climate. Smith⁷ in 1904 pointed out with the aid of graphs the correlation of corn yield with rainfall for June, July, and August, especially for July. In 1914⁸ by means of simple correlation he studied the relation of yield to temperature and rainfall. He found that July was the most important calendar month and precipitation the most important factor. Wallace⁹ in 1920 agreed with Smith that July rain was an important factor but not in all parts of the Corn Belt. He concluded that it was easy to predict corn yield from weather in the south half of the Corn Belt but difficult in the north half. Kincer and Mattice¹⁰ in 1928 found several weather factors, mainly for weekly periods, which gave relatively high correlation coefficients. Mattice¹¹ in 1931 grouped states according to the climatic factors giving the highest correlation coefficients and thereby arrived at a threefold division of the states of the Corn Belt. In that study, too, early-season and late-season factors were first shown to be of considerable importance. Hodges,¹² in an examination of the effect of rainfall and temperature on corn yields in three type-of-farming areas in Kansas, found considerable variation within that state. In 1932 the present writer¹³ showed by means of climographs that in Indiana high temperatures are bad for corn yield and that, other factors being equal, a short season between killing frosts gives a higher corn yield than a long frostless season. Huntington¹⁴ in 1933 used the climograph method to show that climate all through the year, and not merely in the growing season, shows a considerable

⁶ H. B. Wren: Climate and Corn, *Monthly Weather Rev.*, Vol. 29, 1901, pp. 8-14.

⁷ J. W. Smith: Relation of Precipitation to Yield of Corn, *Yearbook U. S. Dept. of Agric. for 1903*, Washington, 1904, pp. 215-224.

⁸ *Idem*: The Effect of Weather upon the Yield of Corn, *Monthly Weather Rev.*, Vol. 42, 1914, pp. 78-93.

⁹ H. A. Wallace: Mathematical Inquiry into the Effect of Weather on Corn Yield in the Eight Corn Belt States, *Monthly Weather Rev.*, Vol. 48, 1920, pp. 439-446.

¹⁰ J. B. Kincer and W. A. Mattice: Statistical Correlations of Weather Influence on Crop Yields, *Monthly Weather Rev.*, Vol. 56, 1928, pp. 53-57.

¹¹ *Op. cit.*

¹² J. A. Hodges: The Effect of Rainfall and Temperature on Corn Yields in Kansas, *Journ. of Farm Economics*, Vol. 13, 1931, pp. 305-318.

¹³ J. K. Rose: Climate and Corn Yield in Indiana, 1887-1930, *Proc. Indiana Acad. of Sci.*, Vol. 41, 1931, Indianapolis, 1932, pp. 317-321.

¹⁴ Ellsworth Huntington, F. E. Williams, and Samuel Van Valkenburg: Economic and Social Geography, New York and London, 1933, Chapter 4.

measure of correlation with corn yields. A still later study by Robb¹⁵ finds fairly high simple correlation coefficients between yield and rainfall for July and August in northeastern Kansas.

PURPOSES AND TECHNIQUE OF THIS STUDY

In the present study of the problem the whole Corn Belt has been dealt with on the basis of numerous selected county units. The correlation coefficients calculated for these samples provide a basis for the determination of transitions from areas in which yield is influenced by one factor or set of factors to those in which it is influenced by others. As a result, more detailed and probably more reliable information regarding the correlation of corn yield with climatic factors within, and just beyond the margins of, the Corn Belt is available. Such information, besides being an addition to geographical knowledge, may contribute toward better crop-yield forecasting by government and private agencies. It is not too much, perhaps, to expect that, if the present trends toward planned agricultural economy continue, some information so gained may be found useful in modifying or changing present agricultural practices.

A second purpose of this study is to illustrate the possibilities of what may well be called "statistical method in geography." Field methods serve mostly for the collection of data. The problem of analyzing these data is complicated by the fact that the geographer commonly works with many variables, independent and dependent. Hence the methods of correlation analysis¹⁶ would seem especially promising tools for geographical investigation.

Several of the writers mentioned above made use of statistical correlation. It is significant, however, that these investigators used state averages for data if they wished to cover a large area or else confined their work to one or two small areas. Such areal units were not suitable for the present investigation, in which it was especially desired to discover such variation as exists from area to area. Fifty-five counties, the smallest units for which yield data were available, were studied. Such a number of counties, well distributed over the Corn Belt and just beyond its margins, covered the area fairly closely and also permitted closer spacing in a few areas for which greater detail was desired. These sample counties were not chosen at random. They were selected with a view to covering the Corn Belt as well as possible, and each county was supposed to have fairly uniform soils, topography, etc. Partly for this reason, small counties were preferred to larger ones. In each county there was at least one weather station, fairly representative of conditions in the county. In the selection of the samples, office work, conferences, reconnaissance, and traverses in the field were supplemented by firsthand knowledge of parts of the Corn Belt.

Inasmuch as it was planned to consider the areal distribution pattern of the coefficients for the Corn Belt as a whole, it seemed best to have data for the several

¹⁵ A. D. Robb: *The Critical Period of Corn in Northeastern Kansas*, *Monthly Weather Rev.*, Vol. 62, 1934, pp. 286-289.

¹⁶ For a simple exposition see Mordecai Ezekiel: *Methods of Correlation Analysis*, New York, 1930. Chapters 3, 4, and 5 are especially recommended to those not familiar with simple concepts of correlation.

states as comparable in period as practicable. In connection with this question, correlations of yield with several climatic factors were run for a number of Iowa counties for three widely different periods. The results obtained showed that, although the coefficients varied somewhat in value with change in the length of period, they did not change greatly in significance: those of little significance remained so, and the significant ones remained significant. Even so, it was necessary to use a shorter period of years in some states, notably Ohio and Minnesota, than was desired.

TABLE I—LENGTH OF LONGEST PERIOD STUDIED

STATE	PERIOD*	STATE	PERIOD*	STATE	PERIOD*
Illinois	22	Michigan	19	Ohio	9
Indiana	22	Minnesota	12	South Dakota	16
Iowa	24	Missouri	19	Wisconsin	16
Kansas	24	Nebraska	24		

*In years. All periods end with 1932.

In all, more than 2000 simple correlation coefficients were calculated and then mapped and the isopleths drawn.¹⁷ In numerous cases the relationship was linear; hence linear correlation was employed throughout. Slow upward trends in the yield data of many of the counties were not eliminated, partly because they were slight and partly because such trends are supposedly due, to some extent, to the effects of complicated and incomplete climatic cycles.

Multiple correlations involving in most cases seven independent climatic factors besides the dependent factor of yield were calculated for 29 counties. The resulting multiple correlation coefficients are shown on Figure 12. The climatic factors included in the multiple correlations commonly varied from one part of the Corn Belt to another. Factors to be included were selected on the basis of the simple correlation coefficients obtained. The results obtained in the multiple problems were calculated for neighboring samples and so as to cover the months May through August.

Two tests of the significance of the coefficients are the numerical value of the coefficient and the question whether or not the coefficient fits into the areal distribution pattern. In this study, if the coefficient is as high as $\pm .40$ or higher, it is of considerable significance, statistically speaking, being three or more times the probable error. Even so, if it stands isolated in the areal distribution pattern of coefficients, its significance is to be seriously questioned.

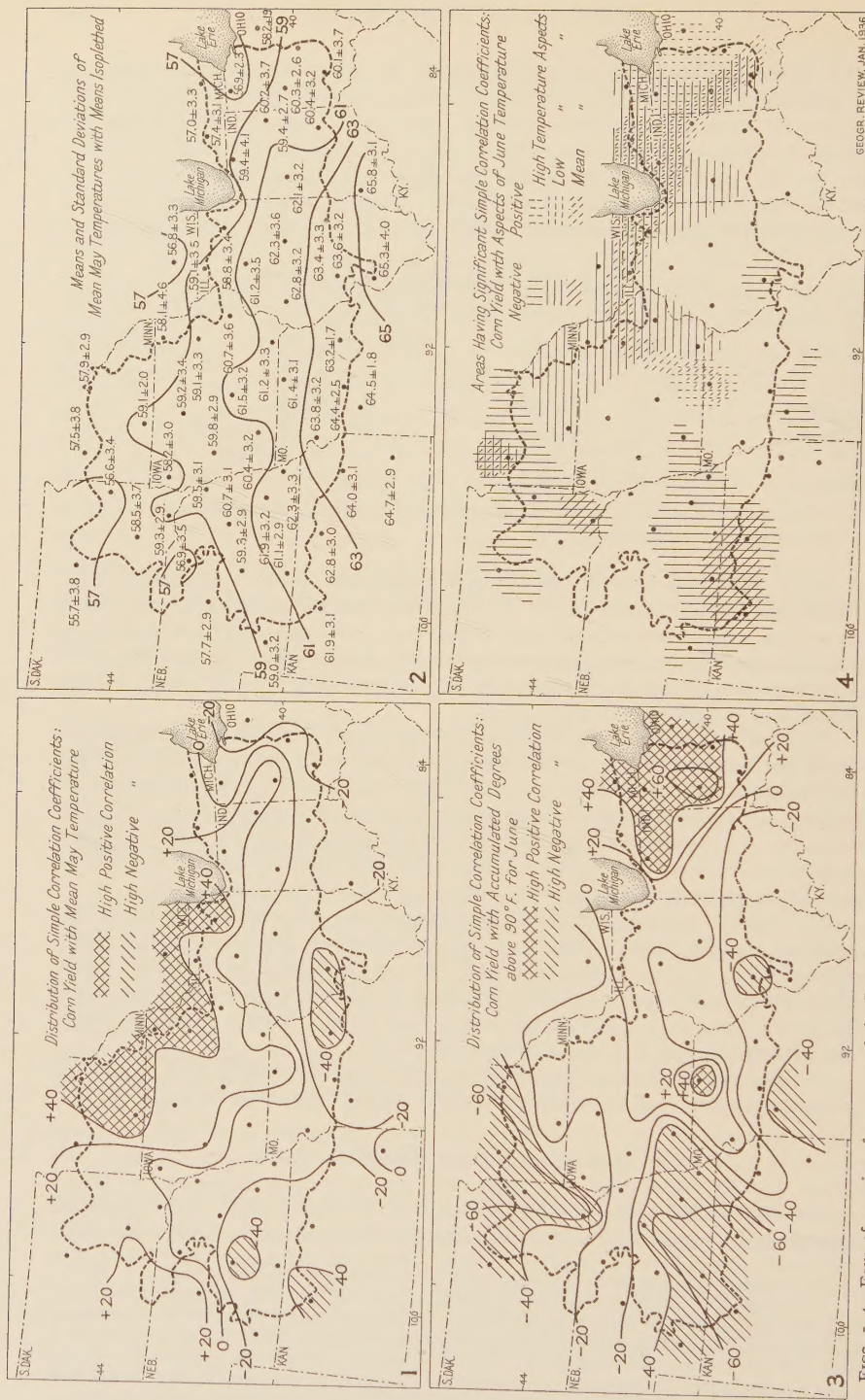
In this investigation simple correlation coefficients of corn yields with 35 climatic factors or aspects of factors were determined for each of the 55 counties studied.¹⁸

CORN YIELD AND TEMPERATURE

An important part of this study has been devoted to correlating variations in corn yield with variations in temperature. Some twenty-

¹⁷ It is suggested that isopleths applied to correlation coefficients be called *isocorrelates*.

¹⁸ The 35 climatic factors and aspects of factors were: for May, June, July, and August: precipitation, mean temperature; for June, July, and August: accumulated degrees above 90° F., days having temperatures 90° F. or above, accumulated degrees below 60° F., nights having temperatures 60° F. or lower, clear days, partly cloudy days, cloudy days, rainy days (0.1 inch or more); length of the growing season measured in days between killing frosts; number of days before June 1 that the last killing frost in spring occurred; July rainfall weighted so as to eliminate the effect of local thundershowers upon a single station in any one year. Other factors and those mentioned for other months were also investigated to some extent.



Figs. 1-4—Four of a series of 12 maps of the Corn Belt showing certain relationships between corn yield and climate. On all maps the broken line shows the boundary of the Corn Belt, and the dots represent the centers of the 55 counties studied (for list see caption to Figs. 5-8). Scale: 1 : 19,000,000.

one maps were drawn up to show the distribution of correlation coefficients between corn yield and various aspects of temperature during the spring and summer months. In general it was found that over large parts of the Corn Belt temperatures correlate more significantly with corn yield than has previously been believed.

Figures 1 and 2 show a sample pair of maps for mean monthly temperature. The areal distribution pattern of coefficients between corn yield and mean May temperature shows the Corn Belt practically halved by the line of zero correlation. It seems from this that variations in mean May temperature have little effect on corn yields throughout the middle zone of the Corn Belt. It may be said that to the north, roughly, the higher the mean May temperature in any year, the better the corn crop; whereas to the south poorer-than-average yields occur after May temperatures above average. It is seen, however, that in these regions only a few of the coefficients are high enough to be called significant. Thus in only a few relatively small areas would a knowledge of the mean May temperature be of much help as an aid in predicting the yield of corn.

Wallace, using state averages, found very low coefficients between corn yield and mean May temperature. Figure 1 helps to explain why that might be the case: such states as Illinois and Iowa are partly negative and partly positive in regard to this factor. Thus positive and negative areas would tend to cancel each other when included in state averages.

The areal distribution of the coefficients (Fig. 1) corresponds fairly well with the distribution pattern of mean May temperature (Fig. 2). Areas in which higher-than-average mean May temperatures are followed by lower-than-average corn yields have May temperatures of above 61° F.; areas of significant positive correlation have temperatures of 59° F. or lower. Comparison of the pattern of correlation coefficients with other supposedly related distributions sometimes gives positive and sometimes negative results. There seems to be a correspondence between the areal distribution pattern of coefficients and the date of corn planting. For areas in which corn is, on the average, planted before May 1 the correlation coefficients are negative; i.e., the warmer the month of May in such areas, the poorer the yield of corn. The yield in areas in which planting commonly is done after May 1 correlates positively with mean May temperature. There seems to be little correspondence between the distribution pattern of coefficients and such factors as soil and altitude.

One temperature factor that yielded surprisingly widespread significant coefficients is accumulated degrees above 90° F. For all three summer months this factor gave significant results. Figure 3 shows the large areas of significant correlation coefficients between corn yield and accumulated degrees above 90° F. for June. Some of

the coefficients are more than seven times the standard error. It is notable that in the southwestern and northwestern parts of the Corn Belt high temperatures in June are bad for corn, whereas in the northeast much warm weather in June seems to be followed by good yields. However, in the area of positive significance there are usually less than ten accumulated degrees above 90° F. Areas having more than 30 accumulated degrees above 90° F. show for the most part relatively high negative coefficients. For this factor correspondence with soil, altitude, yield pattern, and date of planting seems to be lacking.

From an examination of Figure 4 it is plain that June temperature, in one or more of the aspects investigated, has correlated significantly with corn yield in certain parts of the Corn Belt, notably the northeastern, northwestern, and southwestern. On the other hand, it is evident that no coefficient as high as $\pm .40$ has been found for large parts of the region.

June temperatures are significant,¹⁹ highly significant, or even critical in the northeastern part of the Corn Belt. The coefficients are mostly lower than $\pm .60$, but there is no disagreement among aspects; that is to say, high-temperature factors (accumulated degrees above 90° F. and the number of days 90° F. or higher) and mean temperature give positive coefficients, and low-temperature factors (accumulated degrees below 60° F. and the number of nights 60° F. or lower) give negative coefficients. Presumably the corn crop of the relatively humid northeastern part of the Corn Belt commonly needs more heat than it receives during early stages of its growth.

June temperatures are also significant or highly significant in the northwestern and southwestern parts of the Corn Belt. In June, corn is nearing the reproductive stage in the southwest but is considerably less advanced in the northwest. Nevertheless, June heat in both of these subhumid regions of blackerth or chestnuterth soils is too great to favor corn yields. The area of low correlation separating the two regions seems to differ from them in natural factors only in that much of it has deep loess soil.

From the summary map of the correlations of corn yield with aspects of July temperature (Fig. 5) it is seen that the correlations are not to be considered as critical in any part of the Corn Belt. Nevertheless, variations in July temperatures do accompany variations in corn yields in a highly significant manner on the northwest and southwest margins of the Corn Belt and in a significant manner along the whole of the south and east margins. Thus it would seem that July temperatures are somewhat too high for corn along the humid part of

¹⁹ If, of the aspects (high, low, etc.) of a certain factor (June temperature, etc.) investigated for any particular sample, a maximum or near-maximum number gives coefficients above $\pm .40$, that factor is said to be *critical*. If only one of the aspects investigated gives $\pm .40$ or higher, the factor is said to be *significant*. A condition approximately intermediate between significant and critical is spoken of as *highly significant*.

the south margin and decidedly too high on the southwest and northwest margins, where moisture is not plentiful. As for low temperatures, except in an eastern area, July temperatures can scarcely be said to fall so low as to affect adversely the yield of corn.

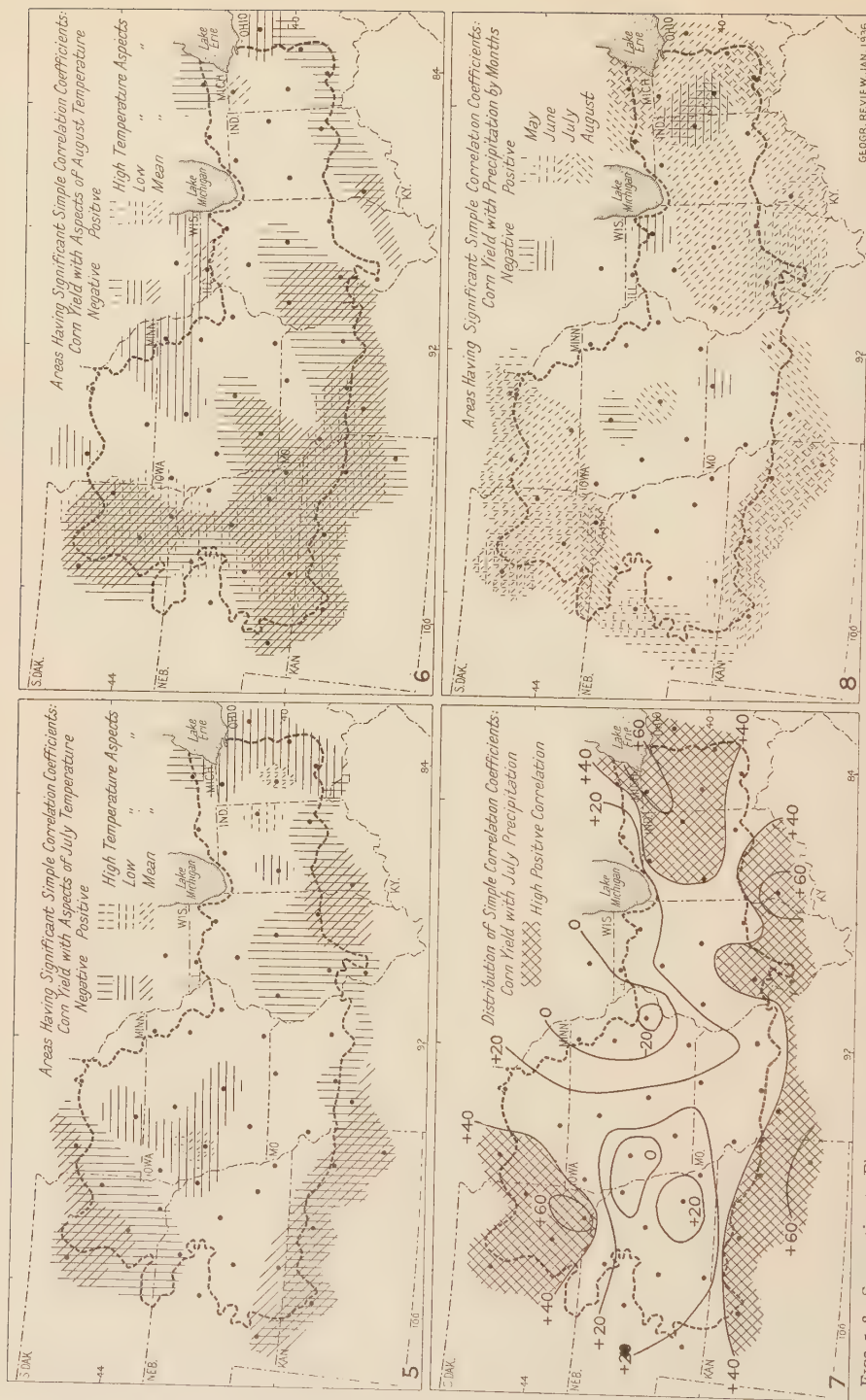
The summary map of correlations of corn yield with three aspects of August temperature (Fig. 6) indicates that August temperatures are to be considered as critical in much of the western part of the Corn Belt. There is no disagreement among the aspects investigated—mean and high temperatures give negative coefficients, and any increase in accumulated degrees below 60° F. is likely to be accompanied by higher-than-average yields. It is worth noting that this western area is one of blackerth or chestnuterth soils and rather scanty precipitation. Along the whole south margin of the Corn Belt high August temperatures seem unfavorable to corn yield. The north margin, particularly in the more humid eastern two-thirds of the Corn Belt, seems to suffer slightly from lack of enough heat during August.

CORN YIELD AND PRECIPITATION

Two aspects of precipitation have been correlated with corn yield in this investigation. Total amounts of precipitation by months for the four months of May, June, July, and August have been considered—with enlightening results. The number of days having precipitation of .01 inch or more for each of the months June, July, and August was investigated—without significant results. In general, this study hardly bears out the conclusions of those earlier investigators who found variations in precipitation to be an exceedingly important factor influencing corn yield.

Of the four months for which variations in precipitation were correlated with variations in corn yield, July gave the most significant results. July rainfall correlated positively with corn yield in 49 of the 55 counties studied (see Fig. 7). The negative coefficients are all too low to be significant. This would seem to indicate that in most of the Corn Belt more-than-normal July rainfall has a beneficial effect on the corn crop, though few of the coefficients are extremely high.

As is shown in Figure 8, variation in precipitation for any of the four months, May, June, July, and August, significantly accompanies variation in corn yield in only slightly more than half of the Corn Belt. The correlation is almost wholly positive; i.e. with the exception of early-season precipitation in two small areas, above-average precipitation is significantly accompanied by an increase in corn yield. In the southwest and northwest and in an eastern area variations in precipitation are highly significant or even critical. In general, early-season precipitation is a fairly good indicator of corn yield on the northwest, west, and southwest margins of the Corn Belt. Midseason



FIGS. 5-8—See caption to Figures 1 to 4. The 55 counties studied, whose centers are shown by the dots, are: S. D., Faulk, Brookings, Davison, Yankton; Neb., Holt, Blaine, Thurston, Platte, Sherman, Hayes, Lancaster, Franklin, Nemaha; Kan., Graham, Cloud, Shawnee, Allen; Minn., Chippewa, Hennepin, Martin; Iowa, Sioux, Winneshiek, Humboldt, Buchanan, Crawford, Polk, Cedar, Adams, Van Buren; Mo., Putnam, Buchanan, Saline, Audrain, Johnson; Wis., Dane; Ill., Stephenson, Kane, Bureau, McDonough, McLean, Macoupin, Coles, St. Clair; Mich., Kalamazoo, Washtenaw; Ind., St. Joseph, Huntington, Tippecanoe, Rush, Knox; Ohio, Fulton, Ashland, Shelby, Franklin, Clinton.

precipitation, on the other hand, particularly weighted July rainfall, seems significant in about half of the Corn Belt, but more so in the eastern, northwestern, and southwestern parts.

The data here summarized indicate that the role of rainfall variations in affecting the yield of corn is by no means simple or overwhelmingly important. Only locally is precipitation a very significant predictive factor.

CORN YIELD CORRELATED WITH MISCELLANEOUS FACTORS

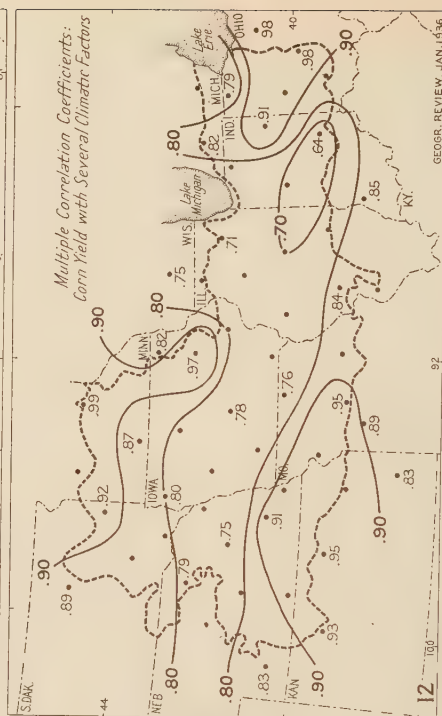
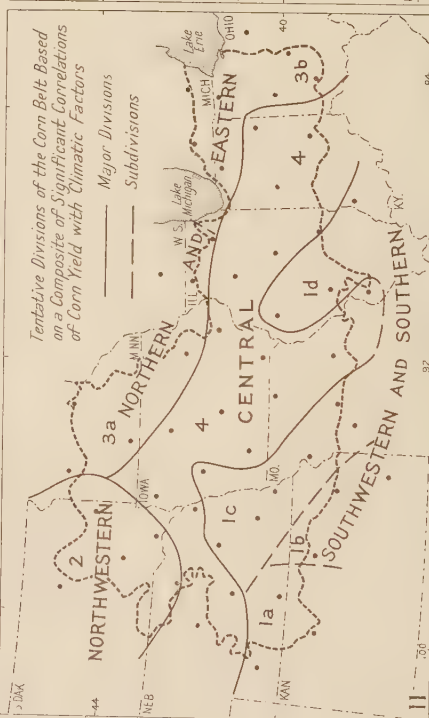
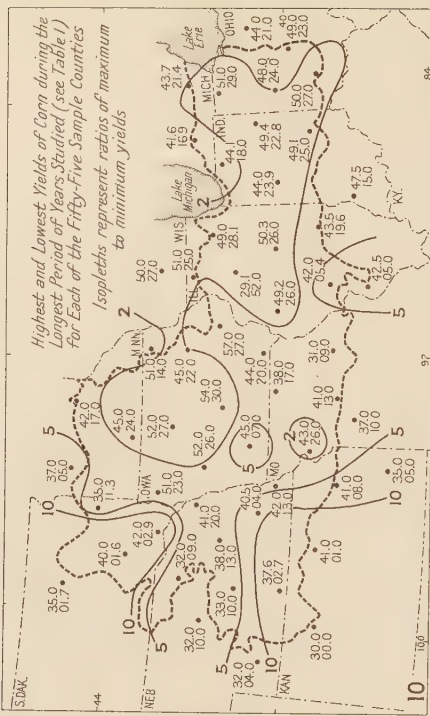
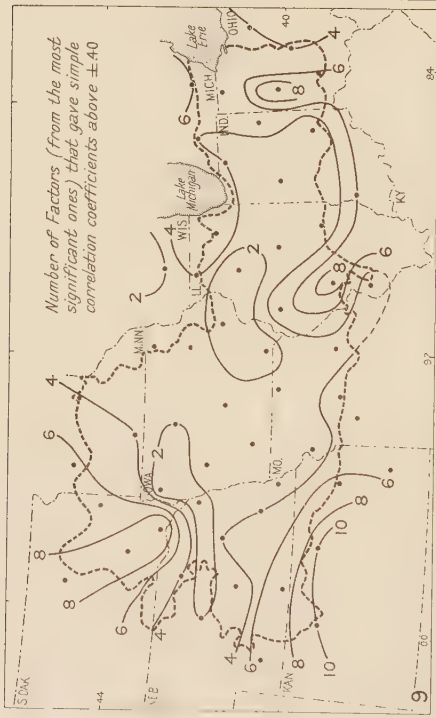
No attempt has been made in this study to correlate with corn yield every possible factor influencing the growth and yield of corn. Other factors than climate have been considered only in an effort to explain the distribution of high and low correlation coefficients between corn yield and climatic factors. Nor have all climatic factors been treated. Temperature and rainfall, presumably the most important, have been treated rather fully. A number of minor factors have also been considered, but with little result. Some of these are of only slight predictive value because basic data for use in computation are as yet largely lacking, others because the correlation coefficients obtained are of relatively little significance.

Insolation data are collected by only a few stations in the Corn Belt. From correlation of yield and insolation for Lancaster County, Nebraska, it may be concluded that insolation in that county either has little effect on corn yield or is so intercorrelated with other factors that its real significance is hidden. Evaporation calculated for Lancaster County—especially evaporation compared with precipitation—correlates negatively with corn yield. For August the correlation coefficient is highly significant ($-.78$). It is to be regretted that evaporation data are not systematically collected at more weather stations. In general, work on factors of cloudiness gave little return.

SUBDIVISIONS OF THE CORN BELT

A general summary of the number of climatic factors important for any county is presented on Figure 9. Only factors showing significant coefficients over a fairly wide area of the Corn Belt were selected.

On the southwest margin variations in as many as ten climatic factors are shown to correlate significantly with variations in corn yield. The northwestern area has nearly as many, and parts of the southern and eastern marginal areas show no paucity of factors giving significant correlations with yield. On the other hand, very few of the climatic factors studied correlate significantly with corn yield in those samples located near the core of the Corn Belt. In Bureau County, Illinois, not one of the 35 climatic factors or aspects of factors gave a



Figs. 9-12—See captions to Figures 1 to 4 and 5 to 8.

simple correlation coefficient as high as $\pm .40$. This would seem to indicate that climatic conditions near the optimum for corn yield exist in the heart of the Corn Belt but act increasingly as limiting factors toward the margins.

Near the center of the Corn Belt mean yields are comparatively high, and although yields fluctuate from year to year (see Fig. 10), no one factor by itself seems to have much weight in affecting the yield. On the other hand, near the margins yield seems to depend on a very delicate balance of climatic factors, which fluctuate widely from year to year and are seldom very favorable to high yields. Here numerous climatic factors are significant, and any one of them has relatively great effect on yield.

On the basis of the summary maps (Figs. 4, 5, 6, and 8) Figure 11, showing tentative forecast divisions of the Corn Belt, was prepared. The boundaries on it are not to be regarded as placed exactly or as unchanging; they are merely an attempt to present general divisions of the Corn Belt on the basis of the present study.

In area 1 midseason temperatures are critical, precipitation and early-season temperatures being of importance in some parts. This is the area of the Corn Belt that has the highest temperatures and has at the same time, in parts at least, scanty rainfall. Further to complicate matters, in parts of this area some of the blackerth and chestnuterth soils have a heavy subsoil that lessens water-holding capacity. The mean yield of corn to the acre is low, though the soil can produce good yields during the rare years when climate is favorable (see Fig. 10).

In subarea 1A early-season precipitation is significant and early-season temperatures are highly significant or critical. So many climatic factors are significant and generally unfavorable to corn yield in this area that it is a rare year indeed when yields of 30 bushels or more to an acre are obtained. Complete failure here is not unknown.

In subarea 1B midseason precipitation is highly significant. Yields here fluctuate widely.

To the north and east, in subarea 1C, no precipitation factor gives significant correlations. This may be due to slightly greater humidity, and probably the loess soils have considerable effect.

Factors of minor significance in subarea 1D are early-season temperatures and midseason precipitation, especially for July. Midseason temperatures seem to be not so critical here as in other subdivisions of area 1.

Area 2 is also one in which midseason temperatures and both early-season and midseason precipitation are significant or highly significant. Here the yield of corn to an acre is rather low as compared with the Corn Belt as a whole. Yields vary greatly from year to year (Fig. 10). The fact that all the samples show at least one year when the yield was 35 bushels or more an acre means that the soil can produce if other factors, mainly climatic, permit.

Area 3 is one in which early-season temperatures are critical. Corn in this area needs more heat during planting and the time of early growth. Even so, the average yields are more than 30 bushels an acre, in some counties even more than 35 bushels. This is very largely an area of gray-brownerths, but other areas with the same types of soil give no such correlations.

As regards climatic factors of minor significance, subarea 3A shows almost perfect transition from northwest to southeast. In the northwestern part both mid-

season temperatures and midseason precipitation are significant; in the middle part—northeastern Iowa and northwestern Illinois—only midseason temperatures remain as a factor of minor significance; and in the eastern part there is no minor factor.

In subarea 3B midseason precipitation and midseason temperatures—one or both—are factors of minor significance. Early-season temperatures become less critical to the south but are highly significant near the east margin.

Area 4 is one in which variations in climatic factors do not seem to be critical for corn yield. A variety of factors give significant coefficients, but there is little possibility of generalization regarding climatic factors significant in the area. The westerly protrusion of this area with slightly significant correlations, extending as it does between two areas in which midseason temperatures are critical, is interesting. A suggested hypothesis is that the loess soil found here does not lose its moisture readily even during the hot part of the season, hence the corn plants suffer very little from temperatures that damage the crop severely in areas almost equally humid to the north and south.

The question naturally arises how well it is possible to forecast the yield of corn for the different parts of the Corn Belt. The map of multiple correlation coefficients (Fig. 12) offers summary evidence that in all likelihood corn yields can be very well forecast in the southwest (subareas 1A and 1B), in the northwest (area 2), and in parts of the north and east (area 3). In other parts of the Corn Belt, especially parts of area 4, the coefficients, though helpful, probably will give forecasts containing considerable error.

CONCLUSIONS

The correlation of corn yield with climatic factors in the Corn Belt of the United States proves to be a very complex problem, for two reasons. In the first place, climatic variables operate not singly but as many-faceted composites. Secondly, not only climatic factors but other factors of the natural and cultural environment change from area to area. Nevertheless, some climatic factors correlate significantly with corn yield in parts of the Corn Belt. Notable among such factors are precipitation and aspects of temperature for May, June, July, and August. It seems to be an unmistakable conclusion, however, that variation in July rainfall is not everywhere so important a factor in corn yield as earlier investigators believed.

No one climatic factor gives significant correlations for all parts of the Corn Belt; nor, apparently, is any one factor of extreme significance in any part of it. Neither for the Corn Belt as a whole nor for particular areas within it does there seem to be, strictly speaking, such a thing as the critical climatic factor, nor is there much evidence of a critical period. Rather, it seems that corn yield in some parts is to be significantly correlated with several—even ten or more—factors covering much or all of the period of growth and reproduction. In other parts significant correlations with corn yield are found for few or none of the climatic factors investigated.

It does seem that of the factors studied variations in temperature are more significant and more critical to corn yield than are variations in precipitation. Also, the midseason period of growth and reproduction is, on the whole, more critical than the early season, except only in the northeastern part.

In general, the significance of the correlation coefficients between corn yield and the factors of temperature and precipitation decreases from the margins toward the center of the Corn Belt. This is true for all margins except the middle of the west one and is outstandingly true for the southwest and northwest margins. It would seem that the south and east margins, fully as much as the north and west ones, are determined by the fact that climatic factors on the margins do not approximate optimum conditions for high corn yield. On the east margin early-season temperatures are commonly too low; on the south margin early-season temperatures are somewhat too high and mid-season temperatures decidedly too high. This suggests that the rather low yields generally returned by corn planted over wide areas south of the Corn Belt may be due to unfavorable temperature conditions that seemingly cannot be counteracted by any amount of precipitation. Coefficients found for three counties in Texas, Tennessee, and Georgia lend substance to this hypothesis.

On the other hand, corn yield in the center or core of the Corn Belt generally fails to correlate significantly with the climatic factors investigated. This is less true for the coefficients of multiple correlations, in which several factors are considered, than for the coefficients of simple correlations. Presumably corn yield in this core area is somewhat affected by the factors significant on the surrounding margins; but, with several factors operative—perhaps first on one, then on the other, side of the optima, and thus with conditions generally favorable—variation in any one factor has little effect by itself.

In general, the areal distribution pattern of significant simple correlation coefficients between corn yield and individual climatic factors shows discordance in its patterns of such natural factors as soil and altitude. It may be noticed, however, that blackerth, chestnuterth, and gray-brownerth areas show several significant coefficients between corn yield and variations in climatic factors, whereas the prairyerth areas show few significant coefficients. This prairyerth area seems to combine optimum soil and climate for corn yield.

The average date of planting and the average yield of corn show only weak correspondence with the patterns of coefficients found. The areas that most lack heat have in general higher yields than areas adversely affected by high temperatures.

There is in most of the cases not much observable correspondence between the pattern of means or the pattern of standard deviations of a climatic factor and the resulting pattern of simple correlation coeffi-

cients. This seems to be partly because corn yield depends largely on several climatic variables operating simultaneously during most of the period when corn is growing and reproducing.

It should be possible to forecast the yield of corn with a high degree of accuracy for several of the marginal areas of the Corn Belt. The multiple coefficients found for the core of the Corn Belt should be distinctly helpful in forecasting but will not provide the high degree of accuracy presumably attainable for the marginal areas. It seems possible that higher multiple coefficients might be obtained for this area by successive elimination of less significant factors.

The present program of the United States Department of Agriculture calls for a considerable reduction in the acreage devoted to corn. This reduction in acreage has been applied as a blanket project to the whole of the Corn Belt. One way of preventing any undesirable surplus of corn would be to remove from corn production those areas that produce corn least well.

In view of the facts discovered in this study, large parts of areas 1A, 1B, and 2 might well be withdrawn from corn production and devoted to other uses. This suggestion is based chiefly on the fact that corn yield in these areas, especially in areas 1A and 2, is commonly so adversely affected in a critical manner by several climatic factors as to be well below the average for the United States as a whole and far below the average for the Corn Belt as a whole. Moreover, these two areas are included in the region where wind erosion is especially damaging to soil resources, and cornland is badly exposed to such erosion. The remainder of the Corn Belt can produce, on the average, as much corn as is now needed.

Finally, the areas for which significant correlation coefficients, for either individual factors or groups of factors, were discovered in this study show no respect for state boundaries. It seems, therefore, that the use of sample counties rather than of state averages gives a more informative solution of the problem, especially those aspects of it that relate to areal variations. Not only sampling but also correlation analysis seems well adapted to this problem and, with modifications, to a wide range of geographical problems.

